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# Scientific Reasoning Is Material Inference:

# Combining Confirmation, Discovery, and Explanation


**Author:**

## Ingo Brigandt

Department of Philosophy

2-40 Assiniboia Hall

University of Alberta

Edmonton, AB  T6G 2E7

Canada

E-mail: brigandt@ualberta.ca



**Note on the contributor:**

Ingo Brigandt is Assistant Professor in the Department of Philosophy at the University of Alberta. His work combines the history and philosophy of biology with epistemology and the philosophy of mind and language by attempting to understand scientific practice and concept use (including its historical change) from an epistemological and semantic point of view. Ingo Brigandt's recent research includes theories of concepts, the rationality of semantic change, and how the context-sensitive use of scientific terms supports successful practice. He is currently principal investigator of the grant project 'Integrating different biological approaches: a philosophical contribution', which is a collaborative project involving several philosophers and biologists that aims at a philosophical account of the nature of theoretical and disciplinary integration in biology. Personal homepage: www.ualberta.ca/~brigandt

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**Abstract**

Whereas an inference (deductive as well as inductive) is usually viewed as being valid in virtue of its argument *form*, the present paper argues that scientific reasoning is material inference, i.e., justified in virtue of its *content*. A material inference is licensed by the empirical content embodied in the concepts contained in the premisses and conclusion. Understanding scientific reasoning as material inference has the advantage of combining different aspects of scientific reasoning, such as confirmation, discovery, and explanation. This approach explains why these different aspects (including discovery) can be rational without conforming to formal schemes, and why scientific reasoning is local, i.e., justified only in certain domains and contingent on particular empirical facts. The notion of material inference also fruitfully interacts with accounts of conceptual change and psychological theories of concepts.

## 1. Introduction

An inference is usually viewed as being valid in virtue of its *form*. Even inductive inferences are assessed in terms of whether they conform to some argument schemas. In contrast, John Norton (2003) recently argued for a material theory of induction, according to which there are no universal schemes of inductive inference—scientific induction is grounded in matters of fact that hold only in particular domains. The present discussion goes beyond Norton's proposal by recovering Wilfrid Sellars's (1953) notion of 'material inference' and arguing that any form of scientific reasoning is material inference. As Section 2 lays out, a material inference is justified in virtue of its *content* (rather than merely its form). More precisely, a material inference is licensed by the empirical content embodied in the concepts contained in the premisses and conclusion. The fact that material inference is tied to the meaning of concepts establishes fruitful connections with the phenomenon of conceptual change in science and with recent theories of concepts in psychology (Section 3). Section 4 shows that material inference covers not only induction (inference involved in confirmation), but also explanation and reasoning involved in discovery. Interpreting reasoning involved in discovery as material inference explains how discovery can be rational without conforming to formal schemes. Thus, the proposal that scientific reasoning is material inference is explanatorily stronger than Norton's account in two major ways. First, the idea of material inference provides an account of what makes scientific inferences rational (if it is not simply their falling under formal schemas). It thereby explains why it is the case that—as Norton observes—scientific induction is fundamentally contingent upon empirical considerations and valid only in restricted domains. Second, the notion of material inference offers a combined treatment of confirmation, discovery, and explanation.

## 2. Induction, Confirmation, and Material Inference

The philosophical search for formal schemas of inductive inference has proven largely futile. For there is a strong trade off between generality and strength: schemas of induction that are of universal scope are either vacuous (circular) or unreliable (fallacious in many instances). John Norton (2003) makes this point by reviewing different kinds of inductive schemes and their flaws, such as inductive generalization, hypothetico-deductive accounts including error statistics, abduction, and Bayesianism.[1] His diagnosis is that we have been misled by deductive logic in thinking that there are universal schemes of inductive inference. In contrast, Norton proposes what he calls a material theory of induction, according to which induction is grounded not in universal schemas but rather in empirical matters of fact. As matters of fact relevant for an induction hold only in certain scientific domains, scientific induction is local. Individual instances of induction may be too domain-specific to be categorized together with other inductions under a general type of induction.

To illustrate this with a simple example (of mine), formal accounts of analogical reasoning as a type of induction construe an inference from an object $a$ having property $P$ to object $b$ having this property as justified in case objects $a$ and $b$ are similar in that they share properties $Q_1$, $Q_2$, …(Salmon 2002). Such a formal account has to acknowledge that the inductive inference $Pa \mid\!\!-\, Pb$ is justified only insofar as the degree of similarity between objects $a$ and $b$ is *significant* and the properties $Q_i$ are *relevant* for the property $P$ to be projected. However, what is relevant or significant crucially depends on features of the particular case, and thus the plausibility of the inference is essentially contingent on empirical information, while the inference's logical form is actually quite insignificant for its validity. For instance, if the question is whether food item $b$ contains a specific protein contained in food $a$, the fact that both are breakfast foods (or other information about their culinary use) is quite irrelevant, while both being made from wheat (or other information about their internal constitution) is much more germane to this analogical inference's reliability. Vice versa, common culinary use is relevant for other inferences involving food items.[2] Thus, inductive inference is grounded in empirical matters of fact and its validity does not seem from its conforming to a particular formal structure.

An objection to Norton's account might be advanced as follows. One could try to accommodate the fact that scientific inference is domain-specific and dependent on matters of fact by sticking to formal schemas of induction, while acknowledging that the soundness of such inductions also crucially depends on the empirical premisses involved. Arguments put forward by scientists are always incomplete, lacking several empirical premisses. One could argue that once these missing premisses are made explicit, a formal inference is reconstructed (possibly approximating a deduction), whose soundness of course depends on these matters of fact. Such formal inductions would be local, as empirical premisses hold only in restricted domains, and a particular schema of induction may be applicable only in some contexts. Norton does not endorse this option, which is shown by how he contrasts a formal and his material theory of induction (2003, 664). On the former there are two distinct ways to increase our inductive abilities: 1) to seek more evidence to serve as better premisses, and 2) to find new valid schemas of induction. On the material theory, in contrast, both issues are entwined and cannot be separated: the acquisition of new scientific evidence at the same time leads to an augmentation of our inductive capacities / principles. However, this observation of Norton's does not really rule out the possibility that scientific inferences are formal inferences usually lacking several empirical premisses, which can in principle be made explicit. A more decisive way to reject formal schemas—and also to explain why acquisition of empirical evidence and enhancement of inductive capacities are entwined—is my claim that all inference is material inference.

Wilfrid Sellars (1953) introduced the notion of material principles of inference (or material rules of inference), contrasting it with formal principles of inference. My aim to recover this idea of his philosophy of science, using the shorter labels *material inference* as opposed to formal inference (previously used by Brandom 1994). Whereas a 'formal inference' is valid due to its logical form, a material inference (not to be confused with material implication and the material conditional) is valid in virtue of the content of the premisses and the conclusion. (The validity may be of higher or lower degree in the case of inductive inferences.) More specifically, a material inference is justified based on the meaning of the various *concepts* contained in the premisses and conclusion. A *deductive* inference is a special kind of material inference, where the validity depends solely on the meaning of the logical terms involved. In the case of inductive inferences, however, the validity of a material inference is contingent upon the various empirical concepts involved. The idea that inference is material inference is stronger than Norton's theory, because it makes claims on the very nature of inference and what makes an inference justified. Apart from also taking a stance on deductive inference, this approach ties into philosophy of language by taking a position on the meaning of concepts. In fact, Sellars (1953, 1974) was one of the early proponents of inferential role semantics (also called conceptual role semantics), nowadays one of the main contenders for a theory of meaning. According to inferential role semantics, the meaning of a term is constituted by how the term figures in inference, and the content of a concept is determined by how it figures in reasoning (Block 1998; Brandom 1994).

On the more standard notion that inference is formal inference, most inferences are enthymematic and valid only if the implicit premisses are explicitly added. For instance, inferring that a given sample of $H_2O$ is solid from the fact that its temperature is below 0 °C would be justified only if at least a premise representing a generalization about the state of water in relation to temperature were added, yielding in fact a deductively valid argument (a deductive-nomological explanation, in case the generalization is a law).[3] On the notion that inference is material inference, however, there is nothing illicit about inferring the solidity of a sample of $H_2O$ simply from its temperature. For the inference is justified not because it meets some logical form, but due to the content of the concepts involved. E.g., the concept '$H_2O$' may include an empirical generalization expressing the relation between the temperature of water and its state of matter (and possibly other law-based properties of water). Pointing to this generalization merely makes the given content explicit. The claim that an inference is justified by the content of the concepts involved does not amount to philosophically vindicating every inference (or solving the problem of induction in a question-begging way) by a magic appeal to conceptual content. Rather, for any inference, the particular empirical content involved has to be scrutinized and defended based on other empirical claims. In the above example of analogical inference, it is an empirical question whether the concept of 'made from wheat' supports inductive inferences about certain proteins contained. Typically, the empirical content of a scientific concept figuring in an inference can be defended based on the history of the concept's change and empirical revision (discussed in the next section). In sum, the adequacy of a material inference is always to be evaluated in terms of whether the content of the premisses warrants the conclusion.

It deserves emphasis that in the context of confirmation and induction the idea that scientific inference is material inference offers an explanation of the phenomena emphasized by Norton. The fact that a material inference is licensed because of the (largely empirical) content of the concepts involved describes how and explains why scientific inductions strongly depend on empirical matters of fact. Induction is local and restricted to certain domains because some of the relevant concepts involved (e.g., 'temperature', 'protein') apply in certain scientific domains only. Consequently, a kind of material inference will apply to a limited number of cases, so that there are no universal inference schemas.

To support this by a case from biology—in line with my later examples—Marcel Weber (2005, Ch. 4) offers a discussion of confirmation in experimental biology. He scrutinizes the oxidative phosphorylation controversy, a debate in biochemistry that started in 1961 with two rival accounts but could not be settled until 1977. Weber dismisses Bayesianism as an adequate account of confirmation, arguing that in this scientific case it would have made problematic normative suggestions about theory acceptance. (On a Bayesian analysis the true biochemical theory should have been accepted too early—in 1966, at a point where the total evidence did not favour one hypothesis over the other.) Deborah Mayo's (1996) error-statistical theory fits experimental biology better than Bayesianism in that Mayo's approach does not assume that scientific inference solely consists of a confirmation relation between theory and evidence and captures the piecemeal production of evidence and scientists' attempts to control for error. However, Weber argues that a statistical notion of error cannot apply to experimental biology, as the relevant reference class for an experiment is unclear, so that no error frequencies can be assigned. Based on the practice of experimental biology and the study of experimental systems, he concludes that epistemic norms used by biologists are not universal rules, but domain-specific, empirical considerations. The notion of material inference advanced here offers a more general positive account of the nature of induction that fits with Weber's criticism of formal philosophical models of confirmation. The idea that scientific inference is material inference explains how an inductive inference used in scientific confirmation can be warranted even if it does not fall under a formal schema, as its strength depends on the contents involved. In the case discussed by Weber, whether an inference is reliable as all disturbing causal influences have been experimentally controlled for depends on the particular empirical content that embodies assumptions about what experimentally relevant influences and controls in this context are.

## 3. Conceptual Change and the Psychology of Concepts

The suggestion is that inference is material inference, being licensed not solely by its logical form, but by the content of the concepts figuring in the premisses and conclusion. I pointed out that the notion of material inference is related to inferential role semantics as an account of word meaning. On the latter approach, rational agents make certain inferences in virtue of the meaning of the terms involved. For a person to associate a particular meaning with a term is to make certain inferences in which this term occurs. Thus, a person makes material inferences and *takes* these inferences to be justified due to the conceptual content involved. However, these inferences may actually be materially invalid or problematic. The reason is that empirical concepts—including scientific concepts—may be based on inadequate empirical beliefs and therefore embody some materially invalid inferences.

For instance, Paul Griffiths (2002) argues that the concept of innateness conflates three properties: a trait being universal within a species, a trait being an evolutionary adaptation, and a trait being insensitive to the environment in its development. Each of these properties is scientifically important, yet they are not co-extensive and empirically to be distinguished, so that the notion of innateness—as it is used by cognitive and some behavioural scientists—often leads to illicit inferences (see also Mameli and Bateson 2006). (Griffiths recommends abandoning the term 'innate' altogether, as its meaning is so entrenched that it inevitably leads to fallacious inferences, and there is no obvious way of redefining it so as to express only one of the three legitimate properties, for which there are already scientific terms.) In a similar vein, Lenny Moss (2003) argues that the term 'gene' figures in two distinct explanatory games in molecular biology. Each of these two sets of inferences motivated by the gene concept is legitimate in its appropriate context, but conflating them leads to fallacious inferences and an inappropriate version of genetic determinism. Moss introduces the concepts ‘gene-P’ and ‘gene-D’ to separate these two sets of inferences conflated by many standard use of ‘gene’. Thus, the idea proposed here that concepts embody various inferences in virtue of their content and that some of these material inferences are illegitimate provides a philosophical explanation of why empirical concepts can be criticized in the first place, and how they may revised—by changing the meaning of a term so that it no longer triggers materially inadequate inferences (or possibly introducing several new terms with empirically more adequate meanings).

This point has obvious connections with philosophical accounts of conceptual change. On Philip Kitcher’s (1993) theory, for instance, a change in a scientific concept is progressive if the revised concept succeeds in characterizing the referent in an empirically more adequate way. Kitcher acknowledges that in the early stages of a scientific field, a certain concept may embody various misconceptions. The concept may (causally) refer to a natural kind though there is no adequate description of it available yet. The concept may initially refer to several natural kinds that are unknowingly conflated, and it may even involve some beliefs that do not pick out an object so that some uses of the term do not refer. In conceptual change these empirical misconceptions are usually cleared up, so that eventually the concept comes to refer to a single natural kind and to embody an adequate theoretical characterization thereof. In my terminology, a concept supports material inferences due to its meaning—inferences that are taken to be justified and have some justification based on prior empirical evidence. Conceptual change is change in the set of material inferences supported by the concept, and it is progressive if it involves discarding materially inadequate inferences and/or acquiring novel materially adequate inferences.

To use the above example about inductively inferring that property $P$ holds of object $b$ if it is known to hold of object $a$ (an analogical inference of the form $Pa \vdash Pb$), whether the predicate $P$ is in fact projectable depends on various empirical factors, including whether it refers to a *natural kind* (Goodman 1955). What an appropriate 'natural kind' is and how much knowledge about it the corresponding kind concept must include to support a given inference depends on the empirical context. The concept $P$ may embody knowledge of the causal basis ('essence') of the natural kind that entails to which kind of objects $P$ is likely to apply, licensing the material inference in virtue of the content involved. In the case of a chemical molecule, its internal structure causally accounts for how it behaves in chemical reactions and thus which properties that hold of one sample of this molecule hold of other samples of this kind (chemical properties, but not all physical ones). In contrast, organisms from different species (e.g. different mammals) belong to the same taxonomic group not because of internal properties, as any genetic and phenotypic similarity can disappear in the course of evolution. Instead, species belong to a higher taxon as natural kind in virtue of their common ancestry—a *relational* property accounts for why these kind members share so many properties (Brigandt 2009). The idea that common ancestry is the essential feature became part of the concept of species and biological taxa only after an important process of conceptual change. Many kinds from molecular biology exhibit their characteristic causal capacities only in certain biological contexts, so that knowing about this is important for the legitimacy of such inferences. Kinds from economics and the social sciences figure in regularities to the extent that certain preference structures or social customs exist. Thus, the projectability of properties can be contingent upon a variety of factors depending on the scientific domain and the particular kind. A natural kind concept may come to include these empirical considerations (corresponding to materially adequate inferences) only after some history of conceptual change.

Both accounts of conceptual change and the philosophical theory of inferential role semantics align with recent trends in the *psychology of concepts* (see Murphy 2002 for an overview). Psychologists assume that concepts are mental structures embodying empirical assumptions that influence the way in which we reason. Experiments are designed to infer the structure of concepts from observable conceptual performances (including verbal reports). There are several specific psychological hypotheses about conceptual structure, but here I focus on the so-called 'theory theory' of concepts as a recent approach. It is motivated and supported by knowledge effects, i.e., the fact that various conceptual performances depend on a large body of a person's background knowledge. Accordingly, the account assumes that a concept is basically a mental theory (hence the name 'theory theory of concepts'). Whereas former psychological theories assumed that concepts are like dictionary entries, the theory theory argues that they are more like entries in an encyclopaedia. More precisely, concepts are mental representations whose structure consists in their relations to other concepts as specified by a mental theory. Psychological studies show that among other things, knowledge effects show up in *induction tasks* (Murphy 2002). Whether a person carries out an induction depends on the type of property that is to be inferred from one category to another, and how this property relates to the domain to which the two categories belong (animals from the same taxonomic group or artefacts with a common use). Thus, inductive reasoning is strongly contingent upon the empirical assumptions embodied by concepts. Furthermore, the theory theory is popular among psychologists studying child development. The development of persons' concepts from young children to adults shows rich patterns of change, involving modification of mental theories. Some have drawn parallels between cognitive development and conceptual change in science, suggesting that psychological studies of how concepts develop based on experience shed light on the cognitive basis of scientific change (Gopnik and Meltzoff 1997).

The claim that scientific inference is material inference is a normative philosophical doctrine about what makes inference rational and how philosophers should study and evaluate scientific inferences. But the psychology of concepts shows that the notion of material inference also exhibits connections to empirical accounts of how people actually reason and draw inferences. The reason is that both on the material inference approach and the psychology of concepts, inferences are made and taken to be acceptable because of the empirical content of the concepts involved. A normative, philosophical evaluation of whether the inference is in fact justified has to be based on whether the conceptual content is empirically adequate and actually support the inference made.

## 4. Scientific Explanation and Discovery

So far my discussion of scientific reasoning as material inference has focused on induction, involved in confirmation. Yet a virtue of the notion of material inference is that it also captures explanation. Similar to inference usually being viewed as formal inference (valid in virtue of its form), traditional models of explanation have construed an explanation as good or scientific to the extent to which it conforms to a particular *formal* schema, be it deductive-nomological and inductive-statistical accounts (Hempel 1965), statistical relevance models (Salmon 1971), or unification accounts (Kitcher 1989). Likewise, models of theory reduction have construed a reductive explanation as a formal deduction from theoretical premisses involving laws (Nagel 1961; Sarkar 1998). In contrast, if scientific explanations are material inferences, then they are to be evaluated in terms of the (empirical) content of the concepts contained in the explanans and explanandum. Although on some construals of inference an explanation is not an inference (Salmon 1971 argued that explanations are neither deductive nor inductive arguments), the notion of material inference is flexible and powerful enough to include explanations. Whereas a deductive or inductive inference used for the purposes of scientific prediction need not be counterfactual supporting, explanations typically are counterfactual supporting. The fact that some material inferences are indeed *counterfactual supporting* was part of Wilfrid Sellars's (1953) original introduction of this notion. His main argument for the need for material rules of inference was that formal rules of inference (in an extensional logic such as Carnap's) cannot capture subjunctive conditionals, which play an important role not only in scientific language but in any natural language. It is insufficient to formalize a law by a conditional added to the system's axioms (a P-rule in Carnap's terminology), as such a conditional does not have the modal force of counterfactuals. In contrast, Sellars argued that scientific concepts embody knowledge about *laws* of nature, thereby licensing counterfactual supporting inferences (Sellars 1948). For instance, in the above example about inferring that a given sample of $H_2O$ is solid from the fact that its temperature is below 0 °C, the concepts of $H_2O$ includes a lawful generalization about the state of water in relation to temperature. In this fashion law-based explanations can be construed as material inferences.

Debates about how to characterize explanation have shown that not all scientific explanations involve genuine laws. But such explanations can be cast as material inferences as well, to the extent that the content of the concept's involved in the explanation is empirically adequate and the content of the explanans is appropriate to account for the explanandum. In the case of *statistical* explanations, the concepts involved in such a type of material inference may pick out properties and appropriate reference classes and link them to statistical relevance relations, which capture for instance the fact that the property to be explained is more probable given the presence of the explanatorily relevant property than given the latter's absence. For the purposes of a *causal* explanation, in contrast, mere statistical correlations (which enable predictions) are not sufficient, and causally relevant features have to be identified. A concept occurring in the explanans of a causal explanation may pick out entities that are part of similar causal processes or governed by the same causal principles. For explanations in experimental biology this often means to describe the behaviour of mechanisms. In terms of material inference this involves concepts that embody knowledge about which natural kinds are part of a mechanism, what their causal capacities are, and how these entities interact with each other.

A material inference is any inference licensed by the conceptual content involved. Material inference is thus a heterogeneous category, including counterfactually robust inferences and inferences not supporting counterfactuals, inferences involved in confirmation and reasoning involved in explanation. While some past models of explanation have focused on certain types of explanation, from the present perspective there is not need to argue that one type is the only appropriate or only basic kind of scientific explanation, as different types of explanation are preferentially used in different branches of science. (Nor is there a need to offer a purely formal construal of what makes an explanation scientific, such as attempts to express in purely syntactic terms when a statement in a DN explanation is a law rather than an accidental generalization, which have failed.) The notion of material inference has the advantage of covering different kinds of explanation depending on whether the concepts figuring in the material inference pick out laws, statistical relevance relations, or causes and features of mechanisms. This latter idea fits with the fact that not only induction, but also explanation is local: a certain kind of explanation holds only in a limited scientific domain governed by certain empirical principles. Whereas philosophers endorsing inferential role semantics have focused on inference—ignoring explanation—the above mentioned psychological approaches to concepts have from the outset studied explanation as a pertinent mode of reasoning. Psychologists emphasize that concepts as mental structures embody knowledge about causes, modal circumstances, functions, or social rules.

Finally, reasoning involved in scientific *discovery* can also be construed as material inference. Many recent accounts of discovery have denied a strong distinction between the context of discovery and the context of justification, or at least rejected the assumption that discovery—unlike justification—is not a rational process and that it should not be subject to philosophical analysis (Hacking 1983; Darden 1991). However, since *formal* inference has been the model of *rational* inference, early accounts of discovery attempted to construe discovery as based on formal schemas. For instance, Ken Schaffner (1974) argued that discovery uses the same logic as confirmation, in fact deductive reasoning—a position that Schaffner himself came to abandon. (In his reanalysis of the biological case addressed by Schaffner, the *lac* operon model of gene regulation, Weber (2005, Ch. 3) argues that this instance of discovery involved a variety of analogical reasoning, in a form that is prohibited in the context of justification.) Another prominent account of discovery in biology was put forward by Lindley Darden (1991) in the context of Mendelian genetics. Influenced by artificial intelligence modelling, she laid out a set of general strategies of discovery, which can be used in various scientific fields. Darden acknowledged that the historical record does not settle whether Mendelian geneticists in fact used these strategies, while arguing that they could have been used in these contexts. However, in his detailed treatment of discovery in experimental biology, Marcel Weber (2005, Ch. 3) rightly objects that Darden's 'could have been used' argument does not settle one important philosophical issue—whether *general and domain-unspecific* rules of discovery (such as those suggested by Darden) are *actually* used by scientists. Weber's alternative position based on the cases he considers is that reasoning involved in discovery is not based on formal rules, but is domain-specific and involves problem-solving heuristics that are particular to a limited range of cases. For instance, he discusses in detail the discovery of the urea cycle by Hans Krebs, arguing that it was based on the use of specific stoichometric considerations and ideas that would not be applicable to discovery problems outside the field of intermediary metabolism.

Weber concludes that what he proposes "is not a return to the older view that the generation of theories is an irrational process that is not open to philosophical analysis, or inaccessible altogether. For to show that a kind of reasoning can be *rational* … is not the same as showing that it employs *general* rules or procedures" (2005, 86). I agree with this idea; however, Weber has not offered yet a satisfactory explanation of how reasoning in discovery can be rational if it neither consists in the use of general rules nor (as he apparently assumes) in the rational inferences used in confirmation. The notion of *material inference* bridges this gap. Scientific reasoning in general—including reasoning occurring in discovery—can be construed as material inference. The content of the various empirical concepts involved in a case of discovery not only motivates the reasoning steps but also justifies their quality. In addition to accounting for what makes reasoning in discovery rational, this idea also explains why 'principles' of discovery are context-dependent, i.e., valid only in a restricted domain and dependent on empirical considerations peculiar to that context.

In sum, material inference encompasses different types of reasoning in science: inductive inference as used in confirmation, scientific explanation, and reasoning involved in discovery. Offering a combined treatment of confirmation, explanation, and discovery is not to say that they are identical. In fact, my discussion emphasized that there are even different types of explanation. The notion of material inference explains why the various inferences used in science can be quite different from each other (as they are dependent on particular empirical contents) and why they cannot be subsumed by a limited set of rules. The philosophical tenet that confirmation, explanation, and discovery are different species of one genus—material inference as rational inference—does not settle the question of what makes a particular instance of scientific reasoning justified. This has to be determined based on an empirical study of the material inference under consideration, so that philosophical examinations of confirmations, discoveries, and explanations are to be continued.

## 5. Scientific Reasoning as Material Inference

Inference has typically been construed as *formal* inference, i.e., as being valid solely due to its logical form. The quality of a *material* inference, in contrast, depends on content of the concepts involved in the inference's premisses and conclusion. What are the reasons for viewing scientific inference and any form of scientific reasoning as material rather than formal inference? Section 2 pointed out that one might accommodate Norton's point that induction depends on matters of fact while sticking—contra Norton—to formal schemes of induction by acknowledging that premisses embodying empirical matters of fact are of course relevant. Likewise, one might wonder why it is not possible to reconstruct every alleged material inference as a formally valid and even deductively valid inference by adding premisses specifying the empirical and conceptual content involved. Even if inferences could be recast as formal inferences, the point remains that their evaluation ultimately depends on the particular empirical and conceptual content involved. But there are two general philosophical reasons for preferring material over formal inference.

First, material inference is a philosophically more fundamental notion than formal inference, in that the former can be used to define the latter but not vice versa. Replacing every occurrence of a term ('photon') occurring in a materially justified inference by another term ('cat') can turn it into a materially invalid inference, as the content of the terms involved influences material validity. Should a material inference happen to fall under a deductively valid schema, however, replacement does not affect its material validity, provided that no logical terms are replaced. Thus, given the notion of material inference, the class of formal, deductively valid inferences can be introduced as that class of inferences that remain *materially* valid under any replacement of non-logical vocabulary (Brandom 1994). However, the class of materially valid inferences cannot be defined from the notion of formal inference, as material validity involves considerations of content not captured by formal schemas. Second, the notion of material inference—appealing to the meaning of the terms involved—respects Wittgenstein's insight that meaning is implicit in practice (meaning is use) and that the competent use of language is possible without being able to lay out explicit rules of language, formulated in some previously learned metalanguage (Sellars 1953, 1954; Brandom 1994). The conceptual content fully (though implicitly) contained in a material inference may be made (partially) explicit by statements specifying the definition of the terms involved. Such 'meaning postulates' could serve as additional premisses to reconstruct the inference as a formally valid one. However, given Wittgenstein's and similar arguments, it is doubtful whether the meaning of terms can always fully be reconstructed by explicit definitions—at least the ability to use language and draw valid inferences does not require this.

Apart from these general philosophical reasons, I adduced several considerations from the philosophy of science that underwrite the fruitfulness of the idea that scientific reasoning is material inference. I explained how this approach interacts with accounts of conceptual change and of how inadequate concepts can be criticized, and with the psychology of concepts. Moreover, the notion of material inference provides a combined treatment of induction/confirmation, discovery, and explanation, while at the same time acknowledging differences among these forms of scientific reasoning. In fact, material inferences form a heterogeneous class, as each kind of material inference is valid only in certain contexts and domains, which is explained by the fact that the validity of a material inference is contingent on the (empirical) content involved. Apart from explaining why scientific inference is local and dependent on empirical considerations, the notion of material inference shows why schemes of induction, explanation, or discovery that are both universal and powerful/reliable are so rare. The heuristic impact of this approach is that it cautions philosophers against attempting to capture what makes an inductive inference or explanation scientific in terms of formal-syntactic conditions, and rather motivates them to pay attention to the empirical considerations germane to an instance of reasoning in science and evaluate it in these terms. Finally, the idea that scientific reasoning is material inference explains how various forms of scientific reasoning—including reasoning involved in discovery—can be *rational* even if they are not based on formal schemas or universal rules.

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## Notes

[1] For an account of what the problems with each inductive approach is, the reader is referred to Norton's detailed discussion, which groups different concrete inductive schemes into different families. In the case of Bayesianism, the issue is that it is a very general but thereby weak

system, which becomes useful only once a large number of conditional probabilities are specified, based on concrete empirical content.

[2] As a referee pointed out, there are more sophisticated formal schemes of analogical reasoning than the one cited above, e.g., approaches in artificial intelligence that model relevance relations by quantitative measures along several dimensions (Ashley 1988). The application of such formal frameworks to concrete cases also requires empirical content about a specific domain, where the number of relevance dimensions and the measures of relevant similarity are computationally determined from information provided about known cases from this domain.

[3] In this context, Sellars (1953) criticized Carnap (1937) as a proponent of the standard notion of material inference, as Carnap introduced empirical principles as explicit premisses, more precisely, as P-rules in his axiomatic system.

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